RE-ORDER NO. 61-472

EXTENDED FEASIBILITY STUDY

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Introduction

Of paramount consideration during our recent feasibility study and breadboard development of instrumentation to measure physical parameters on and below the lunar surface were the weight, space, and power limitations imposed by the limited size of the Surveyor vehicles for which this instrumentation is intended. Now, having completed the above mentioned programs, we shall discuss the question of extrapolation of the Surveyor experiments to later generation vehicles, where not only are weight, space and power limitations greatly relaxed, but where we operate from a mobile rather than a fixed laboratory location.

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For this discussion we assume that rather than 10 lbs. of instruments (as in Surveyor) we may work with 200-400 lbs., and instead of a 1-1/2 in. diameter hole, 3 to 5 ft. deep, we will have a 3 to 4 in. diameter hole (or holes) 30 to 40 ft. deep from which to log or sample the lunar interior.

The discussion divides logically into two parts:

1. Extrapolation of the existing experiments.
2. Proposal of experiments which were impractical to consider for inclusion within the limited payload of the Surveyor missions.

The physical parameters to be measured by the Surveyor instrumentation are as follows:

1. Density - surface and subsurface.
2. Magnetic susceptibility - surface and subsurface.
3. Acoustic velocity - surface and subsurface.
4. Thermal diffusivity - surface and subsurface.
5. Temperature - surface and subsurface.
6. Penetration hardness - surface only.

The following comments relate to proposed extensions of the existing Surveyor instrumentation to second generation spacecraft.

1. Density

No significant improvement is offered for the surface or downhole density apparatus, as proposed for the Surveyor missions.

Direct gamma ray transmission experiments for determination of the density of the lunar subsurface material at first glance appear to offer many advantages. These are experiments in which a gamma source is placed in one hole and the detector in a nearby parallel hole. Difficulty arises as a result of serious deviations from Beer's Law of the gamma ray absorption through a thickness of mineral material which is greater than 6 to 10 cm. These variations are dependent not only on the concentration of specific elements, but upon their

distribution in the matrix. It is felt that experiments requiring such close hole spacing would prove to be impractical.

The gamma-gamma method of density determination, as proposed for Surveyor, when corrected for any significant concentration of hydrogen found to be present in the lunar formations, (Partial Report No. 4[1]) is undoubtedly one of the better measurements which can be included in the second generation systems.

2. Magnetic Susceptibility

For the measurement of in situ magnetic susceptibility, the system as proposed for Surveyor appears to be the best available. With the larger 12.5 in. diameter three-coil system as proposed, errors due to surface irregularities can be reduced to an acceptible level. The smaller 4 in. three-coil system can be used with equal or greater accuracy if provision can be made to produce a plane area of surface on which to work.

If such a plane area is made available, the measurement of dielectric constant becomes practical[2]. Another possible method for the determination of dielectric loss, magnetic susceptibility and electrical conductivity involves the measurement of attenuation of electromagnetic waves (RF) in the material.

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[1] Lunar Physical Parameters Study, Partial Report No. 4, Measurement of Lunar Parameters using Downhole Nuclear Logging Tools, Texaco Inc., November 18, 1960

[2] American Society for Testing Materials, Part 9, p. 1133, Rapid Direct-Reading, Resonant-Circuit Methods for Determining Q Value or Power Factor of Natural Block Mica or Mica Films

If the electrical conductivity is as low as is anticipated, measurements can be made as far as 50 ft. away from a buried transmitter and antenna system. Experiments on (or to be more precise, in) earth have demonstrated the feasibility of this method. Power outputs on the order of 25 watts were adequate in a rather highly conductive region.

3. Acoustic Velocity

Experiments of the same nature as those to be used on Surveyor to determine surface and interval acoustic velocities will be valuable on the second generation spacecraft.

In addition, if 30 to 40 ft. deep shot holes are available, and there is a mobile vehicle from which to work, seismic surveys can be set up to investigate the subsurface structure of the moon.

4. Temperature

With more weight and power available, larger radiometers of greater complexity may be carried. Separate devices for determination of emissivity may be used. Unless conditions greatly different from those specified for Surveyor are found, radiometric methods are probably the most reasonable for temperature determination.

5. Thermal Conductivity and/or Diffusivity

Again, unless conditions are found which differ from those specified for Surveyor, refinements of the instruments

proposed for Surveyor will prove useful in future determination of thermal conductivity and/or diffusivity.

6. Penetration Hardness

The penetrometers, as proposed for Surveyor, can easily be incorporated into the more advanced vehicles along with devices to measure shear strength and load carrying capacity of the surface. Such units could be used to investigate the mechanical integrity of regions over which the spacecraft wishes to pass. Used in this way, they would perform a practical service as well as a scientific function.

The larger borehole planned for the second generation missions allows for the possibility of developing penetrometer units for investigation of the hardness characteristics of the material through which the hole is drilled. It is somewhat questionable as to whether or not such instrumentation would provide sufficient information which could not be deduced from the drilling log and examination of the drill cuttings to warrant adding it to the downhole instrumentation.

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Consideration of future experiments other than extensions of those to be performed by Surveyor quickly leads to the question of what additional information will be most useful in defining the lunar structure. Our discussions on this question

have led us to the conclusion that in addition to crystalline structure and grain size distribution data of the type to be provided by the Petrographic Microscope and the X-ray diffractometer on the Surveyor missions, chemical analysis for specific elements are needed. Silicon, oxygen, hydrogen, and aluminum content will be particularly useful. Our geologists tell us that with a knowledge of these four constituents, and the reasonable assurance that sedimentary formations need not be given serious consideration, we can probably classify the lunar material within one of the classes of igneous rocks found on earth. Furthermore, extreme accuracy is not necessary. If each of these components can be determined to no better than ±10 or 15% of the amount present, significant geologic correlation becomes possible: Classification or a component as either major or trace is of almost as much value.

Having decided upon a line of investigation, the next decision which must be made is this: For the more advanced unmanned vehicles now being considered, where is the point of diminishing returns for in situ determinations? At some point it becomes advantageous to begin devoting payload capacity to the problem of returning lunar samples to earth for further detailed study rather than adding the complexity of necessarily compromised experiments to the spacecraft system. Probably this decision will be based to a large extent upon the availability of a satisfactory sample return system.

We have been concerned thus far with obtaining scientific data concerning the structure of the moon as an end in itself. Since it is planned to deposit people on our natural satellite, we must also give some consideration to what additional information will be required by these early lunar colonists. Can oxygen, carbon and hydrogen be derived from the lunar materials? Do usable ore deposits exist? Are the structural and thermal properties of the moon suitable for the establishment of satisfactory underground shelters? One important property of the lunar subsurface material which will be needed and which is not to be obtained by the Surveyor instrumentation is its permeability to gas flow. A rather straight-forward experiment should be capable of yielding this information.

The following pages will be devoted to brief discussions of some of the above mentioned specific analyses. These are not meant to be complete treatments of the subject at hand, but, rather, are submitted more as nuclei for possible future considerations. We restrict our suggestions to quantitative analyses which can be performed in situ. This avoids the difficulties inherent in the preparation and manipulation of representative samples of accurately known weight.

Differential Thermal Analysis

Differential thermal analysis is a procedure which was first applied by Le Chatelier as early as 1887[3,4]. This technique, although neither very accurate nor definitive, has been found extremely useful in the characterization of certain classes of materials. The differential thermal curves record, within the limits imposed by the sensitivity of instrumentation, all transformations in which heat is taken up or given off. In general terms, this method involves recording the difference in temperature between a chosen "reactive" sample and the same quantity of an inert material having approximately the same density, specific heat, and thermal conductivity, as both specimens are heated at the same uniform and controlled rate. Experimentally, this is usually accomplished by placing the materials to be studied in a symmetrically arranged set of sample holes drilled in a metal block. The junctions of the difference measuring thermocouple are placed at relatively the same position in "reactive" and inert sample, and the block is subjected to a controlled temperature rise in a suitable furnace. It is obvious that the inert sample should follow the block temperature with a small lag. Providing previously mentioned conditions are met, the "reactive" sample should be at the same temperature as the inert sample until a transformation involving the absorption or release of heat occurs.

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[3]Le Chatelier, H., 1887, The Constitution of Clay: Zeitschr. Physick, Chem., V. L, p. 396

[4]Le Chatelier, H., 1887, The Action of Heat on Clays: Soc. Franc, Mineral. Bull., V. 10, pp. 204-211

If heat is being absorbed by the "reactive" sample, its temperature drops below the inert sample at the temperature of initiation of the transformation. The temperature difference and the time duration of the lag are functions of the quantity of heat energy involved in the transformation, the rate at which heat is being supplied to the sample block, the geometry of the system, and certain of the physical characteristics of the sample (density, specific heat, thermal conductivity). It is obvious that any transformation involving the release of heat energy occurring in the "reactive" sample causes its temperature to rise above that of the inert sample, and that the same factors govern temperature difference and time duration of the effect as were mentioned in the case of heat absorption. It has been found useful in certain studies to control furnace atmosphere and pressure[5,6,7]. Stone[8] has described a system in which a continuous supply of fresh gas is passed through the samples at a predetermined pressure.

This semi-quantitative technique for exhibiting reactions of materials on heating has been found useful in mineral and clay studies. The technique is familiar to the geologist and

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[5]Rowland, R.A., and Lewis, D.R., 1951, Furnace Atmosphere Control in Differential Thermal Analysis: Am. Minerologist, V. 36, (1 & 2) pp. 80-91

[6]Saunders, H.L., and Geidroyc, V., 1950, Differential Thermal Analysis in Controlled Atmosphere: British Ceramic Soc. Trans., V. 49, pp. 365-374

[7]Whithead, W.L., and Breger, I.A., 1950, Vacuum Differential Thermal Analysis: Science (new ser.), V. 111, pp. 279-281

[8]Stone, R.L., 1952, Apparatus for Differential Thermal Analysis Under Controlled Partial Pressure of H_2O, CO_2 of Other Gases: Am. Ceramic Soc., Journal, V. 35 (3), pp. 76-82

minerologist, and is considered a useful supplement to X-ray analysis. A sample preparation system would be required in addition to the apparatus for differential thermal analysis.

Either electric power or a solar furnace would be required as a means of sample heating. Development of an automatic sampling, sample preparation, and differential thermal analysis or thermal analysis system is obviously a time consuming instrument development program.

Determination of Elements Present

Theory

The following paragraphs outline the theory upon which certain methods are based to determine the amount of various elements present. The following elements can probably be determined with an approximate accuracy of better than ±25% if the component of the lunar materials of the given element is greater than 10%. In some cases the accuracies may be better than this and in such cases this will be pointed out.

1. Hydrogen (H)

Reference is made to Partial Report No. 4[1]. The basic idea is that the slowing down distance of fast neutrons to epithermal energies depends primarily upon the bulk density and the hydrogen concentration in the lunar material. This slowing down distance is quite sensitive to the hydrogen content for concentrations between 0 and 25% water concentration, varying by

approximately a factor of 10. This distance is usually measured by determining the epithermal neutron flux as a function of distance away from a point source. This could be done in a borehole of multiple points having a spacing of approximately 50 cm. between points.

2. Silicon (Si^{28})

The amount of silicon present can be measured using activation. The Q value for the $Si^{28}(n,p)Al^{28}$ reaction is -3.87 MEV. Thus, using a neutron source, emitting neutrons of energy greater than approximately 4 MEV, will activate silicon. Silicon decays with a 2.3 min. half life, emitting gamma radiation as well as beta particles. There is one complication in the measurement of silicon in that thermal neutron capture in Al^{27} alsc leads to the same final product nucleus. Therefore, it would be necessary to measure silicon by a difference process. For example, place a Ra-Be, Po-Be, or Ac-Be neutron source near the material to be measured. After 10 to 15 minutes, the source would be removed and a gamma radiation detector placed near the material and the gamma radiation, as a function of time, would be monitored for a period of approximately 10 minutes. A second neutron source, emitting maximum energy neutrons less than 3.87 MEV, such as Na^{22}-Be, would then be used and the process repeated. The difference in the amount of 2.3 min. activation would be proportional to the silicon content on the lunar material.

3. Oxygen (O^{16})

The threshold for the $O^{16}(n,p)N^{16}$ reaction is approximately 10 MEV. N^{16} decays with a 7 sec. half life to O^{16} and emits relatively high energy gamma radiation along with beta particles. Again, there is a complication in that the $F^{19}(n,\alpha)N^{16}$ reaction has a threshold of approximately 3 MEV. One would thus use a difference method taking the difference in the 7 sec. activation using a Ra-Be neutron source which emits a maximum neutron of approximately 12 MEV and the activation from a Pu-Be of neutron source which has a maximum energy neutron of approximately 10 MEV. The difference in the activation under the two conditions using equal strength neutron sources would be proportional to the O^{16} content.

4. Aluminum (Al^{27})

Any 2.3 min. half life observed when an activation technique is employed using a Na^{24} or Sb^{124}-Be would be due to aluminum since aluminum is activated by thermal neutron capture. Aluminum would be determined by the background measurement in the determination of silicon.

5. Fluorine (F)

Fluorine may be measured by activating with a Pu-Be neutron source and measuring the intensity of the 7 sec. activation. This is the background measurement for the determination of the oxygen content, and is also a direct measurement of the fluorine content since there are no other known elements which

give a 7 sec. activation.

6. Deuterium (H^2)

Deuterium has a photo neutron threshold of 2.22 MEV. Thus, if one monitored the neutron flux in the presence of a Na^{24} gamma radiation source, which emits 2.75 MEV gamma radiation, the magnitude of the neutron flux would be proportional to the deuterium content as well as the Be content since the photo neutron threshold of Be is 1.66 MEV. One could then use an Sb^{124} gamma radiation source which emits maximum energy gamma radiation of 2.11 MEV to take a background measurement for the determination of deuterium.

7. Beryllium (Be)

As in Item 6, the Be content is measured directly in the background determination for the measurement of deuterium.

Note that no half lives less than 6 sec. or greater than 3 min. are to be measured in the above described methods. It is felt that it would be too difficult to manipulate mechanical devices in a period less than 6 sec. There may be some possibility for activating elements which have half lives greater than 3 min., but these would have to be further investigated.

Using the above activation techniques, there will be some interference from other elements, but it is felt that these measurements can be reduced to practice without too much difficulty.

Reduction to Practice

The above described measurements can be made in a single deep hole (by deep we are referring to a hole perhaps 30-50 ft. deep). Best results will be obtained in a smooth hole of uniform diameter.

A density measurement also has to be made in connection with all of the above described measurements for quantitative work. For the activation work, the general procedure is to lower a point source of neutrons to a specific depth, let the source remain at this depth for a given period of time and then rather quickly move the neutron source from the vicinity of the point and place a gamma radiation detector over this point. For the photo neutron reaction one would simply have a gamma radiation source near a neutron detector. Empirical calibration may be necessary to obtain the desired accuracies, particularly in the hydrogen measurement.

Most of these methods have been reduced to practice. All of these experiments can be done with either proportional or geiger counters. Improvements in the measurement could be made if scintillation detectors and/or multi-channel pulse height analysis were used, but due to the environmental conditions it is doubtful that such would be practical.

Concluding Note

There is one aspect of all of these physical parameters measurements which should be noted: All of the experiments

proposed, except for the measurement of attenuation of electromagnetic waves, are measuring a physical parameter averaged over only a small volume of material, usually less than 0.1 cubic meter. Measurements capable of yielding data averaged over much larger volumes of material would be highly desirable. Estimation of these more gross average properties by statistical evaluation of highly localized data implies that rather low levels of confidence must be applied to the results.

Unfortunately, we have no specific suggestions for experimental solutions to the problem of measuring gross properties of the moon. We have, for example, no surface density measurement which will yield the average density to a depth of 5 or 10 meters. It is recommended that some thought be devoted to consideration of this type of problem. Here, we feel, is an area in which much improvement is needed.

Two experiments which might prove interesting and possibly even useful are these:

1. Measurement of gravitational anomaly produced by surface irregularities such as isolated mountain peaks. Comparison of this observed gravitational anomaly with the value as calculated on the basis of known geometry and using observed density values obtained for the lunar surface and near surface should indicate whether or not these near surface values are representative of bulk densities.

2. Cosmic ray intensity observed as a function of depth below the lunar surface. This would probably be initially of more interest from the standpoint of cosmic ray study than of utility as a tool to investigate gross lunar structure. Some work of this general nature has been done in oil wells on earth. See, for example, Standil and Pringle, Phys. Rev., (101), p. 1395 (1955).